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Conceptualising Changes to Pre-Service Teachers' Knowledge of how to Best Facilitate Learning in Mathematics: A TPACK Inspired Initiative

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Abstract: In 2010, the Australian Commonwealth government initiated an \$8m project called Teaching Teachers for the Future. The aim of the project was to engage teacher educators in a professional learning network which focused on optimising exemplary use of information and communications technologies in teacher education. By taking part in this network, participants were afforded opportunities to transform their practice through a range of localised initiatives that applied information and communications technologies to the art and science of teaching and learning. One of these initiatives involved re-engineering a university mathematics unit targeted at pre-service teachers. Information and communications technologies were purposefully embedded using Mishra and Koehler's (2006) Technological, Pedagogical and Content Knowledge model as a conceptual framework. This paper discusses the outcomes of the initiative. Pre-service teachers and staff involved in the unit shared their stories about the changes they had noticed in both their thinking and practice. The results of the initiative were heartening, and it is hoped that the constructs used will translate into other learning areas.

Introduction

Information and communications technologies (ICT) present significant opportunities for teachers to develop learning environments that help to ensure students are motivated, exhibit minimal behavioural problems in the classroom, and generally engage more effectively in the learning process. However, there is widespread consensus in the research literature indicating that teachers tend not to take full advantage of these opportunities (Cuban, 2001; Groff & Mouza, 2008; Levin & Wadmany, 2008; Sutherland, Robertson, & John, 2009; Voogt, 2008). In their *Partnerships in ICT learning study*, which gathered data from practising and pre-service teachers in every state and territory in Australia, Pegg, Reading and Williams (2007) concluded that teachers in Australia remained largely sceptical about the use of ICT in the classroom. Many school leaders too remain unconvinced about the value of ICT (Dawson & Rakes, 2003; Schiller, 2003). The "problem" with ICT and its relationship to learning, therefore, is that this type of innovation is so massive and complex that it requires the whole system to help generate sustainable change (Fullan, 2003). This context provides the backdrop against which the Australian Commonwealth Government's Department of Education, Employment and Workplace Relations (DEEWR) instigated a substantial and wide ranging project called Teaching Teachers for the Future (TTF).

One of the key aims of the TTF Project was to engage teacher educators in a professional learning network to help build their pedagogical and ICT capacities (Albion, 2012). The project involved all 39 higher education institutions in Australia that delivered undergraduate education programs so the potential for a viable network was strong. The focus on teacher educators was purposeful. In the aforementioned *Partnerships in ICT learning study*, Pegg et al. (2007) argued that pre-service teachers, the future leaders of ICT-rich

provision in schools, should be at the vanguard of change: their ideas and enthusiasm for embedding ICT into teaching and learning are crucial. The TTF Project embraced this viewpoint whilst at the same time acknowledging that each university was unique. The project also recognised that teacher educators could be at different stages of development in terms of their ICT knowledge and skills, and therefore offered some flexibility to project participants in deciding *how* to transform teaching and learning through the use of ICT. The flexibility resulted in an eclectic range of initiatives with varying levels of impact. This paper discusses the impact of one localised TTF initiative that was implemented in a Western Australian university ("the University").

Theoretical Framework

Although each university participating in the TTF Project was given flexibility to implement initiatives that were in tune with its particular constituency, the TTF provided leadership through the articulation of a contemporary framework that sought to better understand the complex relationships between content, pedagogy and technology. The TTF drew upon the insights of Shulman (1987) who posited that teachers constantly engage in pedagogical reasoning processes in striving to engage their students. Through pedagogical reasoning, teachers combine their knowledge of *how* students learn with content-specific knowledge, the synergy of which creates rich learning environments that are tightly attuned to the needs of their students.

The emergence of networked and mobile technologies adds a level of complexity to teachers' pedagogical reasoning processes and some (e.g. Mishra & Koehler, 2006) draw a distinction between teachers' content knowledge, pedagogical knowledge, and technological knowledge. A model describing the relationships between these knowledge-types, and importantly the synergies that are possible through their creative combination, has become known as TPACK (Mishra & Koehler, 2006). TPACK sees teaching and learning about ICT integration as embedded in curriculum methods and professional studies' components of teacher education programs, to enable teacher educators to use ICT effectively in their daily work. The model was adopted by the TTF Project as the theoretical lens in which to conceptualise both the problem of, and potential solutions for, ICT integration.

Design of the Mathematics ICT Initiative

The mathematics ICT initiative that is the subject of this paper was implemented around an existing mathematics specialisation unit which formed part of the Bachelor of Education (Primary). The initiative sought to develop a signature pedagogy (Shulman, 2005) for mathematics where the University teacher educators could model exemplary ICT integration. The focus of the initiative was on primary school pre-service teachers in the third year of their training. The unit - *Teaching Primary Mathematics: Chance and Data, and Algebra* - is offered in second semester each year. The unit is run over 13 weeks and comprises one three hour workshop per week. Assessment comprises an investigative mathematical report (30%), design and reflection of a rich mathematical task (30%) and a final examination (40%).

Teaching Primary Mathematics: Chance and Data, and Algebra is designed to address the content and pedagogy associated with teaching probability and statistics and algebraic reasoning to primary school students. Within an existing framework of learning outcomes and assessment structures, the unit was re-designed with ICT appropriately embedded throughout.

Fifteen pre-service teachers enrolled in the unit in 2010 and 28 enrolled in 2011. Enrolments in the Bachelor of Education (Primary) were 71 in 2010 and 80 in 2011. Therefore, *Teaching Primary Mathematics: Chance and Data, and Algebra* is limited in its potential to influence teacher educators and pre-service teachers at the University as it

represented only 21% of undergraduate primary education pre-service teachers in 2010 and 30% in 2011. However, the small size of the initiative also had its advantages, particularly in terms of project manageability, depth of data collected, and the capacity of researchers to interpret essentially qualitative data within a known context.

The mathematics ICT initiative was undertaken between August and October 2011. Pre-service teachers were team taught by two specialist mathematics teacher educators. Both of the mathematics educators had some experience of embedding ICT into mathematics lessons with school aged students and teachers, but neither had previously attempted this with pre-service teachers. In the past, ICT had been used by the mathematics educators in the tertiary setting mainly as a presentation tool and to demonstrate software to pre-service teachers. It was decided in this unit to present ICT as it might be used in an exemplary classroom, to enable the pre-service teachers to experience it from both a student and a teacher perspective and to see the connection between ICT and pedagogical content knowledge. Team teaching was a purposeful part of the initiative to ensure a consistent pedagogical approach in each classroom. Other benefits of the team teaching approach are discussed by Day and Hurrell (2012).

Pre-service teachers were asked to bring their mobile learning devices in for each workshop. On average, at each session there were enough devices available that pre-service teachers could work in pairs. This arrangement had a decided advantage in that it allowed pre-service teachers to discuss set tasks, and the efficacy of the software used; thus potentially helping to deepen understanding by tapping into the communicative dimension of learning. Although students had appropriate access to ICT hardware during the initiative, the wireless network at the University was inconsistent and this resulted in the focus of the ICT initiative being on software installed on laptops or netbooks (e.g. *Maths300*) rather than more ubiquitous web-based tools (e.g. *GeogebraPrim*, *The Learning Federation*, *Illuminations* and *Gapminder*). This was due to the fact that they were able to actively engage with the installed software, whereas often web-based tools could only be demonstrated.

During the previous two years the pre-service teachers had all studied an ICT unit *Transforming Learning Through ICT* that introduced them to the use of ICT in the classroom, but otherwise they had limited use of ICT in their course. Several units had touched on the use of ICT by demonstrating or suggesting how ICT could be incorporated into teaching, but the pre-service teachers reported that few lecturers and tutors had actually integrated the ICT into their own teaching and learning processes. Most units used a learning management system as a repository of resources and some units had used an online assessment tool.

The mathematics ICT initiative sought to present a novel way in which pre-service teachers could conceive teaching mathematics in their future classrooms. This involved re-thinking what content, pedagogical and technological knowledge was needed by pre-service teachers, but also what overall *learning design* and *learning processes* would complement pre-service teachers' knowledge-base. The TPACK framework (Mishra & Koehler, 2006) was used as a scaffold to guide the integration of ICT into *Teaching Primary Mathematics: Chance and Data, and Algebra*. The idea that twenty-first century learners could benefit through creative educational design using ICT, particularly around concepts of chance and data, was seen as attractive by the team teachers.

The learning design adopted for the initiative was originally developed and empirically tested in a special education setting by Mercer and Miller (1992) and more recently reported by Allsopp, Kyger and Lovin (2007). The design involved taking students through a natural process from the concrete, through a representational phase, and culminating with abstract generalisations and reflection. This process, which for the purposes of this paper is called the C-R-A learning design, is described in Table 1.

Phase	Description	Examples
Concrete	Physically building/manipulating objects.	Playing a game; rolling a dice.
Representational	Using ICT to extrapolate concepts through accessing	Examining population data;

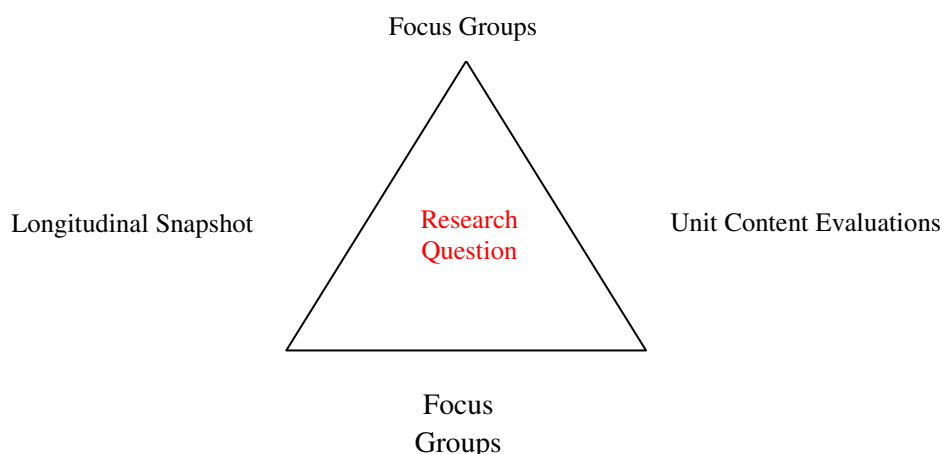
	large data sets or using virtual manipulatives.	lotto results.
Abstract	Using ICT to manipulate large data sets or generalising from pattern generation.	Build alternative scenarios; lotto rules.

Table 1: The C-R-A learning design

Working Mathematically learning processes (Clarke, Goos & Marony, 2007) were embedded into each stage of the learning design. These learning processes included the use of: questioning to encourage students to articulate and build upon their understandings; class communication to generate shared understandings; reasoning to defend and extrapolate decision-making; and reflecting to consider alternative ways of approaching and solving problems. Each lesson provided a meaningful context to enable pre-service teachers to anchor their learning by relating it to something familiar to them.

Methodology

The TTF Project was about instigating systematic change in ICT proficiency of graduate teachers by building the capacity of teacher educators which would then flow on to pre-service teachers. The TPACK model (Mishra & Koehler, 2006) was the conceptual framework selected to underpin the TTF Project. The methodology that underpins the current study integrates three techniques (Figure 1) that combine to inform the core research question: *To what extent did the adoption of the TPACK framework impact on pre-service teachers' ability to integrate ICT into mathematics teaching and learning?*

**Figure 1: Techniques used to generate understanding.**

The three techniques illustrated in Figure 1 were adopted as a way of triangulating data. Denzin (1978) distinguishes between *methodological triangulation* as using more than one method to gather data (e.g. interviews, observations, questionnaires, documents); *data triangulation* over time and space; and *investigator triangulation* which involves multiple researchers in an investigation. This study attempts to do all three. Each technique is now described.

Focus Groups

Each of the pre-service teachers in *Teaching Primary Mathematics: Chance and Data, and Algebra* had the opportunity to participate in one of four focus groups held during week

12 of their course. Students were randomly allocated into one of the focus groups to help ensure an equitable number in each. The number of students involved in each focus group, along with the duration of each session, is provided as Table 2.

Focus Group	No. of Participants	Duration
1	7	42 minutes
2	8	54 minutes
3	7	45 minutes
4	6	56 minutes

Table 2: Details of focus groups convened to collect data from pre-service teachers on the initiative

The rationale for four focus groups was to limit the number of participants per session to eight. It was felt that this would provide an appropriate balance between optimising individual contribution and providing a vibrant communicative setting. Participation in focus groups was voluntary. All 28 students enrolled in the unit chose to participate.

The focus groups were facilitated by two independent academics who used pre-prepared questions to guide the students through the process. These academics were briefed on the initiative and were encouraged to be pro-active in attempting to ensure that all participants in each group were given opportunities to make a contribution. The academics were asked, as much as is possible, to adopt a dispassionate stance to the research and to seek contributions that were honest and trustworthy. Audio recordings were made at each of the focus groups which were then transcribed. Anecdotal notes and photographs of records on a whiteboard were also taken.

University Unit Content Evaluations

University Unit Content Evaluations (2010 and 2011) for *Teaching Primary Mathematics: Chance and Data, and Algebra* were collected and analysed as a way of strengthening the study through methodological triangulation. Examining pre- (2010) and post- (2011) initiative results provided the study with a measure to gauge the impact of the initiative. University Unit Content Evaluations contain 16 items to which participants are asked to respond on a 5 point Likert-type scale from strongly disagree, disagree, not sure, agree, strongly agree. Responses are then attributed a numeric where 1 = strongly disagree, 2 = disagree, 3 = not sure, 4 = agree and 5 = strongly agree. Three items related to content and pedagogy and one overall satisfaction item are reported in this paper. These items are:

- The content and instructional activities of the unit were interesting and stimulating.
- The content of the unit helped me to engage intellectually with the subject matter.
- Activities in the unit enhanced my knowledge and skills in the content area covered.
- Overall, I have been generally satisfied with the quality of this unit.

Although student enrolments in the unit were low ($n = 14$ in 2010 and $n = 28$ in 2011), response rates were satisfactory at 93% in 2010 and 86% in 2011.

Longitudinal Snapshot

The 2011 cohort of pre-service teachers was contacted 12 months after they had completed the *Teaching Primary Mathematics: Chance and Data, and Algebra* unit. All 28 pre-service teachers were asked to keep a record of ICT used in mathematics classes whilst on practicum. At the conclusion of the practicum in 2012 a six item open ended questionnaire was administered to pre-service teachers to gauge what ICT resources and tools had been available to pre-service teachers in school settings, what ICT were used by supervising and pre-service teachers, and what rationale underpinned the selection of ICT. These questions were posed to help explore the extent to which students had adopted the approaches to ICT integration modelled in the unit, both in mathematics and other subject areas. Responses to the above questions were collected immediately after the students' 12 week classroom internship (i.e. in their fourth year of study whilst located in a school). Seventeen responses were received representing a response rate of 61%. Although the response rate was low, the longitudinal snapshot was considered worthy of inclusion in the study. Data triangulation over time can provide strong evidence on the extent to which knowledge and skills gained during an initiative can survive and readily transfer to other contexts.

Data Analysis

Four academics conducted the data analysis of the transcriptions from the focus groups, unit content evaluations and longitudinal snapshot in an attempt to synthesise the data and consider how sentiments expressed by students related to the TPACK framework. The analysis, which was conducted through a series of face-to-face meetings, followed three stages based upon Morse (1994): comprehension of the data, identification of relations and linkages, and theorising about how and why relations and linkages appear as they do.

Findings

The core research question that guided the current study sought to gauge the impact of the initiative in terms of pre-service teachers' abilities to integrate ICT into mathematics teaching and learning. The initiative adopted TPACK to present ICT as a readily available tool that might underpin a sophisticated pedagogical approach. This approach was adopted on a week-by-week basis through the C-R-A learning design.

Focus Groups

The key message arising from the focus groups was that implementing a pedagogical approach to promote higher order learning was transformative for the pre-service teachers involved. Conceptions of ICT changed from viewing ICT as a motivational and/or drill and practice tool to seeing possibilities in terms of student-centred discovery and collaborative problem-solving. As some pre-service teachers in the focus groups put it:

It's not so much the actual activity but it was the way it was taught, the process you go through. There was a framework that we followed and also how you integrate the ICT into it. (Group One, 1)

With the technology, I didn't realise how much further you can take a maths question. From the concrete materials you can go into the software to increase the sample base to take the problem further to extend the kids' learning. (Group Two, 1)

The effective structure of using ICT in a lesson changed how I would use it properly rather than just as a fallback. (Group Four, 3)

These sentiments were commonplace in the qualitative data and represent a shift from using ICT to “get an answer” to exploring the mathematics, finding new questions and applying knowledge. Pre-service teachers now believed that ICT can be used to pursue deep mathematical learning:

That was pretty cool. You played the game as if you were at the fair and then made up some new rules. Then you could put those rules into the software and see what would happen and then make better rules for a better game. (Group Two, 8)

Pre-service teachers understood that a shift to higher levels of thinking was contingent upon giving students the locus of control over ICT, encouraging them to manipulate and ask questions of the data, and evaluate the results of modifications that they had made. Pre-service teachers acknowledged that exploration and investigation using ICT encouraged students to work together to solve problems and to reflect on their learning. As two pre-service teachers explained:

We actually got to experience it ourselves. We worked together to solve problems just like the kids would, and we learnt what it would be like for the kids and then we thought about how we had found out new things and what that meant to us as teachers. (Group Three, 1)

The interaction with other people was good, the pair work etc. It helped us to learn the maths just like our students would. (Group One, 2)

Being able to efficiently simulate real situations and generate large quantities of data facilitated a connection with mathematics that could not have been accessed within a traditional classroom setting. Examples of these sentiments from focus groups include:

You can actually use ICT to support the learning. You can look at lots of data without having to plot lots of graphs. (Group Four, 4)

It would be impossible to simulate 36 years of lotto results without ICT. (Group Two, 8)

Embracing a lesson structure where ICT was a *partner* in the learning process (Goos, 2005) was seen by pre-service teachers as providing more opportunities for students to take charge of their own learning. Focus groups strongly highlighted that pre-service teachers perceived that ICT integration assists in the movement from a teacher-centred classroom to one where student-centred activities are front and centre. As one pre-service teacher explained:

ICT is a tool to extend their [students'] learning. Rather than using the software as a motivator or to show a video, you can use it to extend ideas. You can encourage the kids to use it rather than the teachers using it. (Group One, 3)

The scope for exploration and investigation was seen by pre-service teachers as preferable to a teacher telling the students what to do in a step-by-step fashion. Student-centred learning was felt to encourage students to choose their own directions and options, and manipulate the data as they saw fit. There was a widespread consensus that better learning outcomes would emerge when a teacher handed the locus of control over ICT to students. The importance of actually using the ICT themselves as students, rather than having it demonstrated and then discussing classroom applications, was highlighted by a number of pre-service teachers:

They let us discover it for ourselves rather than telling us. We got to see it like the kids would. (Group Four, 6)

I used to think maths was about you standing up there and trying to get the kids to understand, but now I know the kids can actually use ICT to learn maths. You can use ICT to consolidate and develop concepts. (Group Two, 6)

The focus groups conveyed a positive and upbeat impression of the initiative, particularly its impact on pre-service teacher's knowledge and attitudes towards ICT integration. To help triangulate this technique, the quantitative and qualitative components of 2010 and 2011 University Unit Content Evaluations were analysed to check for confirming or disconfirming evidence.

Unit Content Evaluations

As discussed, University Unit Content Evaluations contain 16 items to which participants are asked to respond on a 5 point Likert-type scale from strongly disagree, disagree, not sure, agree, strongly agree. Responses were then attributed a numeric where 1 = strongly disagree, 2 = disagree, 3 = not sure, 4 = agree and 5 = strongly agree. A mean score for each item was calculated for pre- (2010) and post- (2011) initiative cohorts. Four items were scrutinised from the purposes of this paper. Three related to content and pedagogical approach and one related to overall satisfaction. These items are shown in Table 3 along with mean scores for 2010 and 2011 cohorts.

Item	Mean 2010 n =15	Mean 2011 n = 28
The content and instructional activities of the unit were interesting and stimulating.	3.57	4.54
The content of the unit helped me to engage intellectually with the subject matter.	3.43	4.46
Activities in the unit enhanced my knowledge and skills in the content area covered.	3.43	4.58
Overall, I have been generally satisfied with the quality of this unit.	3.84	4.38

Table 3: Mean scores for selected Unit Content Evaluation Items: 2010 and 2011

Although the number of responses is low, it is notable that mean scores on all items increased markedly. The largest increase (+1.15), *Activities in the unit enhanced my knowledge and skills in the content area covered*, would seem to fit with the teaching approach modelled through the initiative. Pre-service teachers clearly enjoyed the balance between the concrete, representational and abstract. This sentiment was also expressed in qualitative comments made in the 2011 Unit Content Evaluations:

Hands on activities were useful and effectively taught. (UCE, 21)

I valued the hands on learning experiences that were provided to us. (UCE, 13)

The use of ICT was great to enhance our learning. (UCE, 23)

Linking ICT in the classroom, class activities, stimulating conversation. (UCE, 17)

It is interesting, though, that positive sentiments made about ICT usually accompanied comments about content and/or pedagogy. For example, "I liked the use of concrete materials and ICT" (UCE, 20); "I valued the use of ICT in relation to classroom teaching" (UCE, 19); "The hands-on learning and the use of ICT was great" (UCE, 7). These comments indicate that ICT is perceived by many pre-service teachers as integrally related to either content and/or pedagogical knowledge, and that the construct of technological knowledge may in fact be artificial.

Longitudinal Snapshot

The longitudinal snapshot revealed that pre-service teachers (coded “PST”) were still enthusiastic about the way in which the initiative modelled mathematics teaching and learning 12 months after the *Teaching Primary Mathematics: Chance and Data, and Algebra* unit:

I am a strong believer in facilitating learning this way. It not only addresses content knowledge but also caters for learner diversity in the process. (PST 1)

I used it [C-R-A] all the time. I introduced concepts with concrete materials and then let the students apply what they’d learnt through ICT - mainly iPads and interactive whiteboards. (PST 9)

Further, many pre-service teachers were enthusiastic about the possibilities of transferring the C-R-A design into other learning areas:

I have used it in many of my lessons while I was on 10 week prac this year. I used it during Science lessons, English lessons and Maths lessons. (PST 12)

I used it mostly in Maths and in the Literacy block. It was the only way to get the concept across to the kids. (PST 8)

Pre-service teachers explained that although they may not be teaching Chance, Data or Algebra during their internship, they now have a process of working from the concrete to the abstract incorporating ICT to design better lessons, no matter what strand of mathematics, year group or indeed learning area they were working with.

The longitudinal snapshot, however, revealed a number of barriers identified by pre-service teachers. These are set out in Table 4.

Barrier	Examples of pre-service teachers’ sentiments
Time it takes to properly plan for the C-R-A approach to learning.	Even in a well-resourced school, planning with the technology still required “double planning” in case of tech problems. (PST 2) I do still believe that modelling is a fantastic way to teach, although it does take some time to prepare and organise each lesson. (PST 12)
Availability of ICT in the classroom.	I agree with the approach but think it depends on the classroom circumstances and resources available. (PST 4) Children did not have access to computers, but I used a hands-on, concrete approach where possible to introduce concepts. (PST 7)
Perceived ability of students to progress to abstract thinking.	I did not always move to abstract concepts due to the level of experience students had with abstract thinking. (PST 2) Kids need more time with the concrete. (PST 8) My classroom teacher preferred concrete through representation – no abstraction. (PST 11)
Knowledge and skills of mentor teachers.	I have not seen other teachers use this framework. Only ICT first, then concrete, then abstract. (PST 3) I have not seen other teachers use these frameworks. (PST 12) I haven’t witnessed teachers using these frameworks very much. (PST 10)

Table 4: Barriers to the implementation of the teaching and learning delivered during the initiative

Overall, the longitudinal snapshot revealed that the initiative had some long-term impact on the pedagogical values of the pre-service teachers involved. Despite significant barriers, the synergies between the types of knowledge that were needed to teach mathematics to twenty first century learners (expressed through TPACK), augmented by a practical learning design (C-R-A) and student-centred, accountable learning processes (Working Mathematically), combined to provide a constructive and functional learning setting.

Focus groups, Unit Content Evaluations and the longitudinal snapshot suggest that pre-service teachers were inspired by what they saw as a novel approach to using ICT in mathematics modelled through the *Teaching Primary Mathematics: Chance and Data, and Algebra* unit. This approach was said to promote higher order thinking through student-centred discovery and collaborative problem-solving. The Unit Content Evaluations confirmed high levels of pre-service teacher satisfaction in terms of content and instructional materials used for the *Teaching Primary Mathematics: Chance and Data, and Algebra* unit. Most pre-service teachers were enthusiastic about applying the C-R-A learning design in their fourth year internship and beyond. Although in the internship a number of pre-service teachers came face to face with some challenges to implementing their version of the learning model proto-typed in the initiative, most pre-service teachers in the study maintained a high level of enthusiasm for the potential of the model.

Discussion

Returning back to the core research question which guided the study - *To what extent did the adoption of the TPACK framework impact on pre-service teachers' ability to integrate ICT into mathematics teaching and learning?* – it is first necessary to untangle the various roles TPACK, the C-R-A learning design and the Working Mathematically learning processes actually had in the initiative. Figure 2 illustrates how the initiative was conceived in terms of beliefs, knowledge and actions.

Beliefs □	Knowledge □	Actions	
		Learning design	Learning processes
Philosophy about how students' best learn: for example, learners construct their own understandings rather than it being imparted on them by a teacher.	TPACK Technological: ICT as a cognitive tool. Pedagogical: active, constructive, problem-based, communicative and reflective learning. Content: Chance and data, algebra.	C-R-A: consistent movement from concrete, through representational and culminating in abstract thinking.	Working mathematically: questioning, communicating, reasoning, reflecting.

Figure 2: Conception of the initiative in terms of underlying beliefs, knowledge, and practical actions.

It is argued that an effective learning environment is one where there is coherency between underlying philosophical beliefs about how students best learn, the types of knowledge required (technological, pedagogical and content) to best facilitate student understanding, and the learning design and processes needed to generate student buy-in. Conversely, learning becomes problematic when there is dysfunction between these elements and/or when one or more element is not appropriately balanced with others. For example, one of the probable reasons for the strong pre-service teacher support of the initiative was the balance between TPACK and the learning design. Figure 3 shows how the C-R-A learning design integrated into TPACK, and involved making judgements about when and when not to use ICT.

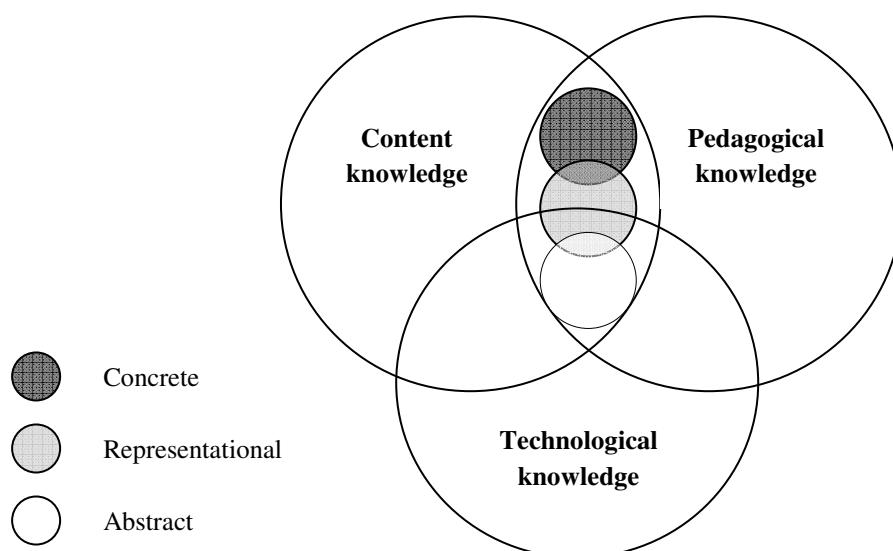


Figure 3: The integration of TPACK with the C-R-A learning design.

The concrete phase usually involved using tactile hands-on materials which integrated pedagogical and content knowledge, but did not involve ICT (the dark circle). Representational activities harnessed ICT when it made sense to extrapolate concepts via accessing large authentic data sets (the shaded circle). Abstract thinking almost always involved manipulation, analysis and synthesis of data and therefore ICT was heavily used for these forms of higher order thinking (the clear circle). The underlying pedagogical reasoning that links technological, pedagogical and content knowledge with learning designs has been described in recent literature as “instructional planning activity types” (Harris & Hofer, 2009). This type of planning or reasoning is a complex matter and it is suggested that following the processes outlined in Figures 2 and 3 are a useful starting point. Other issues to consider are the nature of the content, identified learning outcomes, desirable assessment practices, ICT availability and skill levels of teachers, and the needs and capabilities of learners.

The mathematics ICT initiative experienced problems with network connectivity and this somewhat limited the ICT solutions on offer. For example, resources on the Web were only demonstrated (not used by pre-service teachers for either creative work or inquiry), and there was no use of Web 2.0 tools to collaborate outside of the physical environment. The creative use of ICT therefore focused on one or two admittedly impressive software applications. These software applications were chosen on the basis of their capacity to engage students in active meaning making (Jonassen, 2002) including the creative use of data to build understandings.

Had the ICT components of TPACK been more complex (e.g. included Web 2.0 tools for online collaboration), then this may have negatively impacted on the learning design. For this initiative, simplicity and replication were key. Over a 13 week period, pre-service teachers bedded down their beliefs, knowledge and actions in a way which was lasting. The downside of the approach was that pre-service teachers were not exposed to a broader range of technological solutions. Simplicity worked for the initiative, but did not serve pre-service teachers particularly well during their internship where most did not enact the learning model that they had engaged with during the initiative. However, the level of impact of the initiative was such that it still remained on the radar of pre-service teachers as an aspirational goal one year after the initiative concluded. The C-R-A learning design was pivotal in embedding higher order learning into nearly every lesson in the initiative. Table 5 provides an example of how a lesson on probability was conducted prior- and post-initiative.

Lesson Steps	Prior to ICT initiative	Post ICT initiative	Added-value through ICT ^a
1	Context Set context through a story shell.	Context Set context through a story shell.	
2	Concrete/Manipulative Play 10 “Win at the Fair” games per pair on a physical board.	Concrete/Manipulative Play 10 “Win at the Fair” games per pair on a physical board.	
3	Representational Collect and record data to total prize payouts and compare with takings.	Representational Collect and record data to total prize payouts and compare with income.	
4	Compare data from each pair and discuss similarities and differences.	Compare data from each pair and discuss similarities and differences.	
5	Discuss how short-run and long-run data may differ.	Discuss how short-run and long-run data may differ.	
6		Play game on computer to see if short-run data stands up over the long-run.	Applying
7		Use “Demonstration” mode of Maths 300 to develop a computer model that replicates the concrete form of the game.	Analysing
8		Use “Auto” mode of Maths 300 to run multiple trials of the concrete form of the game (up to 100,000 times).	Analysing
9	Abstract Discuss the perception of bias in the game. Hypothesise and construct a game with a level of bias that is appropriate for a school fete (pen and paper).	Abstract Discuss the perception of bias in the game. Hypothesise and construct a game with a level of bias that is appropriate for a school fete (the software allows prize amounts and rules to be changed).	Analysing Creating
10		Test your hypotheses with multiple trials. Generate instant feedback to determine if your strategies produce the required results. Refine and improve your rules and prize amounts if appropriate.	Creating
11		Extend the problem. What happens if?	Evaluating
12	Discuss perceived elements of bias in developing a board game.	Discuss perceived elements of bias in developing a board game.	Evaluating

^aUsing revised Bloom’s Taxonomy (Anderson & Krathwohl, 2001)

Table 5: Probability lesson prior- (2010) and post-initiative (2011)

The initiative did not denigrate the way in which the unit was taught previously. Rather, it sought to test the efficacy of an approach underpinned by learning theory which suggests that students learn best when they are afforded opportunities to engage with authentic learning activities in a supported environment (Herrington, Oliver & Reeves, 2002). The use of ICT in the probability lesson, as described in Table 5, augmented learning at representational and abstract phases of the lesson. At the representational level, the advantages of using ICT tended to be associated with the broadening of possibilities from increased data-sets. Learning gains at this level were noted in the application of data to other contexts and more sophisticated analysis. At the abstract level, learning gains through using ICT were more

aligned with the manipulation and extension of data-sets. In these circumstances, teachers were able to personalise students learning in accordance with their grasp of concepts, where possible encouraging them to engage in higher order thinking such as synthesis and evaluation.

Mercer and Miller (1992) reported considerable learning gains for adolescent special education students when they tested what they termed the CRA instructional sequence for basic mathematics curriculum. More recently, Allsopp, Kyger and Lovin (2007) posit that moving from concrete, through representational and abstract activities will help students with learning difficulties to better understand mathematical concepts. Witzel, Mercer and Miller (2003) compared the CRA instructional approach to traditional instruction with students in general education classes and found that those who had used a CRA instructional approach outperformed students with whom a more traditional approach had been used. Souza (2008) explained that the newer research in cognitive neuroscience supported the use of a CRA approach with all students. The current study found that the C-R-A learning design was valued by pre-service teachers not only to enhance their own understanding of mathematics, but also as a future method for teaching mathematics and even teaching more generally. The C-R-A learning design, therefore, holds some promise, and perhaps transferability, outside of the original special needs context. Further studies involving larger samples are needed to test this proposition.

Pre-service teachers' sentiments about their experience resonate with the literature, for example, concurring with Bai and Ertmer (2008) and Steketee (2005) that the model of integrating ICT within a subject context was more powerful than relying on a general ICT unit to learn how to integrate ICT. Equally, pre-service teachers appreciated the experience of having time to explore the software, use it to solve real problems and work collaboratively with their peers as students before examining how this related to teaching (Haydn, 2010).

The focus of using ICT authentically and effectively to develop deep mathematical learning and concept development rather than concentrating on how to use the tools themselves was the window through which the pre-service teachers viewed the development of their own content knowledge and encouraged them to examine their own pedagogical beliefs (Lim, Chai & Churchill, 2010). This challenged their pre-conceived notions of what mathematics classes should look like. The initiative allowed pre-service teachers to see the possibilities for learning using ICT in their classrooms and consequently making the learning more accessible to their students (Lawless & Pellegrino, 2007; Steketee, 2005). Coupled with this was the sense that the pre-service teachers were aware that they needed to be critical users of ICT, deciding if, when, what, how and why to use ICT to improve the learning outcomes for their students (Bate, 2010; Lawless & Pellegrino, 2007; Ozgun-Koca, Meagher & Edwards, 2009/10) rather than just to entertain or motivate them.

Importantly, pre-service teachers identified that the software with which they were able to personally engage and interrogate, developed familiarity and confidence thus enhancing opportunities for use in the classroom. They did not feel confident enough to use software that they had only seen demonstrated, even though lengthy discussions about how it could be used in a classroom had occurred. Niess et al. (2009) suggest that teachers progress through a five stage developmental process in choosing to integrate a particular ICT into mathematics teaching and learning. This process is shown as Figure 4.

	1	2	3	4	5
	Recognising →	Accepting →	Adapting→	Exploring →	Advancing
Characteristics	Teachers see the alignment of ICT with mathematics teaching and learning	Teachers form favourable attitudes towards using ICT in mathematics teaching and learning	Teachers make a conscious decision to adopt ICT in mathematics teaching and learning	Teachers actively integrate ICT into mathematics teaching and learning	Teachers evaluate the results of their decision to integrate ICT into mathematics teaching and learning

Figure 4: Niess et al.'s (2009) five stage developmental process in integrating ICT into mathematics teaching and learning.

The key message arising from this study is that transformation of teaching practices through ICT is possible where beliefs, knowledge, learning design and learning processes are aligned. As the initiative progressed, pre-service teachers exhibited a more discerning approach to ICT integration critiquing available software, knowing what to look for, and knowing what can be used to develop and support deep mathematical learning. Software that had previously seduced pre-service teachers was now seen as rather superficial and “flashy”. At the conclusion of the initiative, quality software was gauged by how it develops mathematical thinking and concepts and how it works alongside concrete materials. This indicates a development in technological knowledge.

The impact of the C-R-A learning design and the Working Mathematically learning process certainly led to more sophisticated conceptions of ICT amongst the pre-service teachers taking part in the project. For example, where an ICT was *demonstrated* in class (e.g. the Gapminder web site), this resulted in pre-service teachers recognising or accepting the pedagogical value of this ICT (i.e. stage 1 or 2). However, when pre-service teachers were *guided through* the C-R-A learning design and the Working Mathematically learning process (e.g. using the Maths 300 tool), a more adventurous and long lasting approach to ICT, akin to reaching Niess et al.'s (2009) adapting or exploring phases seemed to emanate (stages 3 or 4). Maths 300 is designed around rich investigative tasks which complement and are complemented by a C-R-A approach. There is an expectation that students will have worked with manipulative materials before moving to the computer simulations. Many of the software activities allow students to take ownership of the learning, by encouraging them to investigate what would happen if certain parameters were changed. This rich investigative approach works particularly well in statistics and probability, and algebra. It would therefore seem that the requirement for investigation and manipulation that complements the C-R-A approach leads to more desirable teaching and learning outcomes. As a demonstration approach to teaching and learning is quite common amongst curriculum methods educators (Hsu & Sharma, 2006) it would appear that the efficacy of this practice should be addressed.

Limitations of the Study

There are some specific limitations that need to be acknowledged in this research. The initiative was a small study of only 28 students, run over a 13 week period in a Western Australian university. As such, it is limited in its generalizability to other contexts. Secondly, the team teaching approach with class sizes of 14 is an exception to general university teaching. This almost certainly had the effect of positively skewing student perceptions of the initiative. The pre-service teachers enrolled in the *Teaching Primary Mathematics: Chance and Data, and Algebra* unit as an optional specialisation. Therefore they may have been more open to mathematical concepts than pre-service teachers who may have to undertake mathematics units on a compulsory basis. Finally, there was inconsistent WIFI in the teaching

environment which limited the range of ICT that could be used in the initiative. This caused the focus to be on installed, rather than, web-based software.

Conclusion

The use of TPACK to underpin a learning design and associated learning processes was enlightening in this small scale study. By modifying practice and modelling how to integrate ICT in the teaching and learning process within the mathematics classroom, the study addresses Lawless and Pellegrino (2007) and Lim, Chai and Churchill's (2010) concern that relying on specific ICT courses to prepare pre-service teachers is inadequate. Despite identified limitations, the success of the model used for integrating ICT into the teaching and learning process was heartening, and it is hoped that the conceptual frameworks used will translate well into other learning areas.

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